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ARMORED MEDICAL RESEARCH LABORATORY

FORT KNOX, KENTUCKY

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PROJECT NO. T-13 - SURVEY OF FOOT MEASUREMENTS AND THE
PROPER FIT OF ARMY SHOES

First Partial Report On

Study of Factors Bearing on the Establishment of Size Tariffs,
on Size Designations, and on Shoe Fitting.

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Project No. T-13

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4 December 1945

ARMORED MEDICAL RESEARCH LABORATORY
Fort Knox, Kentucky

SPMEA 727.3
AMRL Project No. T-13
SGO Project No. 611

4 December 1945

1. PROJECT: No. T-13 - Survey of Foot Measurements and the Proper Fit of Army Shoes. First Partial Report - Study of Factors Bearing on the Establishment of Size Tariffs, on Size Designations, and on Shoe Fitting.

a. Authority: 1st Indorsement SPMDO 421.3-ASF-SGO, Washington, D.C., dated 24 September 1945.

b. Purpose: To define by field study and quantitative measurement:

- (1) The relationship of shoe size to the incidence and type of foot casualties;
- (2) The influence of marching and weight bearing on foot size;
- (3) The role of socks in determining shoe size; and
- (4) The importance of the wearer's judgment of fit on the selection of shoes.

2. DISCUSSION:

a. The criteria which the Army now uses for fitting shoes are adaptations from civilian practice. As such they may not be entirely appropriate to military requirements. Yet, with the present limited knowledge, a properly designed and fitted shoe can only be defined as one which does not, in any way, contribute to foot injury, and thereby military ineffectiveness, regardless of climate or conditions of use. It would be desirable for the proper spatial relationship or dimensional tolerance between the various foot surfaces and the apposed inner shoe surface to be expressed with precision. Lacking this, approximations are of practical usefulness.

b. Fundamental to the establishment of dimensional tolerances, are the following considerations pertaining to basic shoe design:

- (1) The existence of many different foot shapes may make a single style of shoe improperly conform to the feet of some individuals even though the intrinsic shoe dimensions be correct. Anthropometric studies now in progress at the Laboratory are expected to provide information on this aspect of shoe fitting.
- (2) The effectiveness with which the posterior part of the shoe is secured to the tarsal and heel region of the foot, (whether by means of laces, or by some other device, such as straps) determines the degree to which wedging of the forepart of the foot in the shoe must be relied upon to avoid looseness of fit.

(3) The kinds of materials used and the type of shoe construction influence the dimensions of shoes and the manner in which they are fitted. The following are regarded as some of the aspects of shoe design requiring further study, not only because shoe sizing is contingent upon them, but also because the successful prevention of foot casualties demands their consideration.

(a) Thermal factors: Insulation, heat dissipation, water permeability, and rates of wetting and drying.

(b) Physical protection: From ground and brush injuries, and from insect and other animal bites.

(c) Mechanical factors: Flotation and traction.

(d) Structural considerations: The extent of the need for structural assistance or "support" within the shoe for the normal soldier's foot, including shaping of the sole, and upper, and the use of a rigid shank; proper shoe weight and heel height; flexibility at the ankle for convenience in using driving pedals; and ease of putting on and removing the shoes. In addition, the thickness and resilience of the sole determine the necessity for rocker construction.

(e) Sources of irritation: Location of seams, wrinkling of upper material, counter stiffness, and nailing.

c. In view of these considerations, this study which was performed with shoes of present design, affords only partial information on the complex subject of shoe fitting.

3. CONCLUSIONS:

a. Thoroughly conditioned troops have worn service shoes, reversed upper, composition sole, fitted as much as a size or a size and half in length, longer and shorter, and as much as two units in width, wider and narrower than their feet measured on the Clark Device called for, and have marched 13.7 miles daily for approximately two weeks over varied terrain in summer heat.

b. Under these conditions, five times as many casualties were associated with the wearing of small shoes as with large.

c. This tolerance for large fitting suggests that the dimensional intervals between sizes may be increased. A size tariff containing fewer sizes than are now provided thereby becomes permissible.

d. When present Army shoes are fitted oversize, the lacing fails to secure the shoe to the foot; and the throat of the shoe must be padded to maintain approximation of the wearer's heel to the shoe. If the means of attachment be made more flexible in this regard, so-called "large" shoes might be worn more generally with satisfaction.

e. The dimensions of the feet of normal men are not significantly influenced either by prolonged marching or by weight bearing.

f. Present data suggest that heavy socks alter the foot dimensions which are taken for purposes of shoe fitting to a significant degree only when close fitting is practiced.

g. Soldier resistance to the fitting of unaccustomed shoe sizes is minimized when the size designation is not revealed.

4. RECOMMENDATIONS:

None.

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APPENDIX I

THE RELATIONSHIP OF FOOT DIMENSIONS TO SHOE DIMENSIONS IN THE PRODUCTION OF FOOT CASUALTIES

INTRODUCTION:

1. It has been reported previously that misfitting of shoes is frequent among troops. To correct this, it is believed that redesign of Army shoes is essential and that a prerequisite to this is a program of systematic anthropometry of soldier's feet. Preparatory to the collection of measurements, it became necessary to know how closely soldiers' shoes should fit the outlines of their feet, or alternately, how much larger shoe dimensions may be than those of the feet. Not only the conventional measurements of length and width are involved but many others in several planes, diagonals and circumferences, over the whole irregular surface of the foot. Obviously, unless some freedom of dimensional variation between the foot and shoe is permitted, no quantity manufacture would be possible, and custom fitting would be essential.

2. Studies were accordingly conducted to establish by experience what space was permissible between feet and shoes. This could only be done in terms of present Army shoes, even though they are of relatively imperfect design, both with regard to their shape and proportionate dimensions, and with regard to factors independent of considerations of size per se, such as flexibility, location of seams, weight, method of closure, water permeability and insulation properties.

METHODS:

3. For the tests 30 soldiers were marched 400 miles during a 32-day period, exclusive of Sundays and holidays. The standard course was 13.7 miles long over rolling country, approximately one-third on concrete road, one-third on improved dirt road, and one-third on unimproved dirt road. The actual net marching time was 4 hours and 20 minutes daily, at a rate of 119 paces per minute. A short break was allowed at $3\frac{1}{2}$ and 10 miles and a longer break at 7 miles for lunch. Water and salt were provided ad libitum. Typical Fort Knox mid-summer conditions were encountered; these are graphically presented in Figure 1. The standard uniform consisted of fatigues, pistol belt and canteen. Leggings were omitted because: (1) they are no longer standard, (2) it was believed that they restrict leg muscle action and possibly circulation, (3) they alter the effective shoe size due to the strap attachments, and (4) they interfere with the ventilation of both the leg and foot.

4. The criteria utilized in the selection of the troops were as follows: (1) no recent hospitalization for any cause; (2) no known foot disability which had proved an impediment to marching in the past; (3) creditable company performance in the judgment of the first sergeant; and (4) no record of infraction of Army regulations. Thus troops were obtained who were expected to make willing subjects, and who would not be expected to possess gross foot abnormalities either functionally or anatomically. Height, weight and other data concerning them are summarized in Table 1.

TABLE 1
DESCRIPTIVE DATA OF 26 OF THE TEST SUBJECTS

	<u>Mean</u>	<u>Range</u>
Age (yrs)	21.7	18-27
Height (inches)	68.5	65-72
Weight(lbs)	159.5	139-226
Duration of Army Service (mo)	27.2	8-57

5. Daily clinical examinations were made of the men's feet. Complete records were kept of all lesions and untoward sensations, and of the relationship of these events to the shoes being worn. Only one pair of cotton or cotton and light wool socks were worn and the men were permitted neither to remove their shoes on the march nor to use powder. These precautions were taken since conditions could thus be kept standard and since the study actually pertained to shoes, the imperfections of which might have been masked by the use of powder, heavier socks, or periodic removal of the shoes.

6. Because none of the troops had had any marching practice within the 3-month period prior to the experiment and many of them had had little prior to then, even during basic training, the first 19 days of the test were regarded as a period of conditioning, during which time one of the men was dropped from the experiment and 6 others were excluded from the principal experimental group because of the persistent occurrence of foot lesions. As of the end of the experiment, the men who were included in the critical test group were those who were obliged to drop out from the march because of foot disabilities for less than 5% of the total marching schedule, while those excluded had dropped out from 10% to 33% of the total time.

7. By the 20th day, it was felt that all lesions due to poor conditioning or to inherent anatomical or functional defects had become either corrected or manifest. Accordingly on this day, the remaining 22 thoroughly conditioned subjects were fitted with shoes such that on one foot a small shoe was worn, and on the other foot a large shoe was worn. On the 22nd day these shoes were reversed, and on the 28th day they either were reversed again or new shoes were issued, one still smaller and the other still larger than the previous ones. Only new service shoes, reversed upper, composition sole, without toe caps were used.

8. The sizes worn by the men are indicated in Table 2 where they are compared with the "appropriate" size as indicated by the Clark Measuring Device. Although this device is the one currently approved by the Army, it is, as are all other shoe measuring devices, a purely arbitrary method of arriving at shoe size in terms of a limited number of foot measurements. Moreover, it fails to take into account peculiarities of foot shape and dimensional attributes other than length and width. Accordingly, no criterion other than judgment actually exists to define proper fitting. For this reason, and because the primary purpose of this study was to evaluate the tolerable range and limits of so-called "misfitting", no special effort was made to observe subjects marching with shoes fitted precisely in accordance with the Clark Device scheme. The

choice of sizes was actually based on the relationship between the length and breadth of the foot and the interior of each shoe. The shoes ranged in length from 2 to 28mm longer than the foot and from 0 to 23mm narrower. Such measurements, although more precise than shoe size designations, have limited meaning since for length they describe only the length available for the longest toe and for width they do not take into account the fullness of the upper vamp leather, since the breadth measurement of the shoe was taken as that of the broadest diameter of the insole. When the large shoes were worn, it was almost always necessary to insert felt pads between the tongue and lacing stays to keep the foot in place in the heel of the shoe. Without this expedient the shoes could not have been worn, not only because of abrasion from rubbing but because walking would have been almost impossible due to the lack of secure attachment of the shoe to the foot.

9. The measure of narrowness is not as precise a one as is the measure of length relationship since the breadth of the foot was measured at its greatest ball thickness while the breadth of the shoe was measured at the maximum horizontal breadth of the insole. The foot actually has available the additional space provided by the fullness of the upper leather across the vamp in which to spread out over the insole, seams and welt. When this happens, the shoe is not too narrow in a strict sense, but the tread of the foot does overlap the side seams and fails, on its lateral edges, to rest on the solid sole structure.

TABLE 2

SHOE SIZE TESTED ON 22 CONDITIONED SUBJECTS COMPARED WITH THE
" APPROPRIATE " SIZE AS INDICATED BY THE CLARK DEVICE

NAME	FOOT R or L	DAY OF TEST			SIZE INDICATED BY CLARK DEVICE
		<u>20th</u>	<u>22nd</u>	<u>28th</u>	
Bak	R	10-3E	9C	10-3E	10E
	L	9C	10-3E	9C	
Bar	R	9½-4E	8C		9E
	L	8C	9½-4E		
Bel	R	10½-3E	9D		10D
	L	9D	10½-3E		
Bro	R	9½-4E	8C	9½-4E	9D
	L	8C	9½-4E	8C	
Buf	R	10½EE	9D		11EE
	L	9D	10½EE		
Cal	R	10EE	8D	10EE	9EE
	L	8D	10EE	8D	
Cam	R	10½-3E	9D	11-4E	10½E
	L	9D	10½-3E	9C	
Cra	R	8-3E	7D	8-3E	8-3E
	L	7D	8-3E	7D	
Dye	R	10EE	9C	10½-3E	10D
	L	9C	10EE	8½E	
Fir	R	7½-4E	6½D		7½E
	L	6½D	7½-4E		
Hav	R	10½EE	9D	9C	10E
	L	9D	10½EE	11-4E	
Kna	R	9-3E	8D	9-3E	9½C
	L	8D	9-3E	8D	
Lys	R	11C	12½E	10½C	12C
	L	12½EE	11C	13-3E	
Maya	R	7E	9E	7E	9E
	L	9E	7E	9E	

TABLE 2 - Continued

NAME	FOOT R or L	DAY OF TEST			SIZE INDICATED BY CLARK DEVICE
		<u>20th</u>	<u>22nd</u>	<u>28th</u>	
Mel	R	9D	10½EE		10½C
	L	10½EE	9D		
Rus	R	8D	9-3E	8D	9EE
	L	9-3E	8D	9-3E	
Sin	R	8D	9-3E		8½EE
	L	9-3E	8D		
Vas	R	7EE	8½EE	7EE	8½D
	L	8½EE	7EE	8½EE	
Voz	R	8½E	9½EE		9E
	L	9½EE	8½E		
Wea	R	8½E	10EE	8E	10E
	L	10EE	8½E	11-3E	
Woh	R	10C	11EE	9½C	11½B
	L	11EE	10C	11½EE	
Woo	R	6½E	8½EE	6½E	8½D
	L	8½EE	6½E	8½EE	

RESULTS:

10. The wearing of small shoes was much more frequently responsible for those foot lesions generally associated with the wearing of shoes of improper size than was the wearing of large shoes. With regard to the lesions of the dorsum of the great toe due to rubbing by the redundant upper leather, improper proportioning of upper fullness to shoe breadth and the use of unyielding leather are to be incriminated rather than faulty fitting. The infrequency of heel lesions when larger shoes were worn may have been due, at least in part, to the padding at the throat of the shoe, which kept the heel in place. This is not a consideration of size as customarily understood but of shoe proportioning. As pointed out in a preceding report*, current shoes which are not closely fitted to the forepart of the foot are almost universally too loose for the heel. In summary, of the 22 conditioned subjects who wore small shoes on one foot and large shoes on the other for 13 days, from the 20th to the 32nd day of the test, a total of 286 man-days of testing, there occurred only 36 lesions, none of them of great severity, and only about half of them severe enough to necessitate dropping out for part of a day's march; 30 of these 36 lesions were associated with the wearing of small shoes, as shown in Table 3.

*AMRL Project No. T-10 - The Design and Fit of Army Shoes.

TABLE 3

INCIDENCE OF LESIONS APPEARING ON THE FEET OF 22 CONDITIONED MEN MARCHING
13 DAYS WEARING A LARGE SHOE ON ONE FOOT AND A SMALL SHOE ON THE OTHER

(Total of 286 Man-days of Marching)

	Small Shoe(a)	Large Shoe(a)
Blisters or tenderness of tips or plantar surfaces of one or more toes	9	0
Aggravation of corns	5	0
Blisters or tenderness under 1st metatarsal heads	7	1
Blisters or tenderness under heads of other metatarsals	4	1 (b)
Blisters on heel rim	2	0
Tenderness over Achilles insertion	3	1
Blisters on dorsal surface of great toe	0	2
Tenderness above malleolus due to chafing of shoe top	0	1
	<hr/> 30	<hr/> 6

(a) In those instances in which a lesion appeared in association with a small or a large shoe, disappeared when the shoes were reversed and reappeared with the return to the original fitting, the lesion is counted twice.

(b) This lesion had been noted previously and may have become manifest independently of the size of shoe worn.

11. Thus, it appears that the fitting of shoes on men conditioned for marching need not be precise. Large shoes seem to possess a measure of advantage, provided they are held snugly to the heel, in that fewer lesions result from them than with small shoes; and in addition, a greater variety of sock combinations may be worn inside them. It may be concluded from this that fewer sizes than now provided are actually necessary to fit troops, since the tolerance for large fitting seems to be greater than is generally supposed.

APPENDIX II

OTHER FACTORS AFFECTING THE FITTING OF SHOES

The Constancy of Foot Size:

1. It has been presumed that prolonged marching and extra weight bearing increase foot size enough to be taken into account in shoe fitting. It is a common belief, for example, that the shoes, even of healthy individuals without peripheral venous stasis, are tighter at the end of the day than they are at the beginning. Army practice at some stations calls for the soldier being fitted to hold heavy weights in each hand when his foot measurements are being taken to allow for supposed size increases with weight bearing. A preceding report (vide supra) pointed out the fallacy of these beliefs and practices and suggested that under a variety of circumstances the feet of marching troops do not change in size materially.

2. Observations have been repeated in this study to further verify the fact that a single foot measurement with the subject standing, at any time of the day, and in any stage of training, and regardless of weight load, provides a sufficiently accurate statement of foot size for shoe fitting. Figures 2, 3 and 4 show respectively the order of the changes in foot length, ball breadth, and heel breadth dimensions after a day's march of 13.7 miles, after 32 days' marching, totaling 400 miles, and with weight bearing (20 kg in each hand - 88 lbs. total). The alteration in foot dimensions under these three conditions are seen to occur in both directions, some smaller and some larger, the great majority being grouped within 3 mm plus or minus the initial measurement. This order of difference is but very little greater than the accuracy with which the measurements may be reproduced and is, therefore, of small significance. Accordingly, the dimensions of the feet of standing, normal men may be said, for practical purposes, to be unaltered by excessive weight bearing or by marching.

The Influence of Sock Thickness:

3. The increase in foot dimensions produced by various types of socks has been determined in order to ascertain whether the choice of shoe size would be significantly influenced thereby. Table 4 shows the result of careful measurements of a foot covered by various combinations of currently standard Army socks. The change in the dimensions of the sock covered foot is shown to be of much smaller order than the range of shoe size which may be worn without discomfort or disability by marching troops. This is not to say that the individual is unaware of the presence of increased sock thickness. It is not clear, however, whether it is the dimensional change alone that evokes this awareness. It is possible that rougher weaves associated with greater specific surface enhance the adhesiveness of the sock to the shoe; and as a consequence, diminished freedom of foot movement within the shoe may be experienced. Measurements, of course, do not take account of the possible effect of wrinkling of the sock within the shoe. Other measurements of several subjects made by different observers, and also by photography, confirm the data in Table 4.

TABLE 4

INFLUENCE OF SOCK OF VARIOUS TYPES ON THE RIGHT FOOT SIZE OF ONE SUBJECT

	<u>Length (mm)</u>	<u>Width (mm)</u>	<u>Girth at Ball (mm)</u>	<u>Size by Clark Device</u>		
Nude Foot	272	105	257	9½E+ interpreted as 9½EE		
Wearing:						
Sock, wool, light, 73-S33220	272	102	257	9½E+	"	" 9½EE
Sock, wool, cushion sole, 73-S31828	274	104	262	9½E+	"	" 9½EE
Sock, wool, cushion sole, 73-S31824	276	106	260	9½EE	"	" 9½EE
Sock, wool, heavy, white, 73-S32238	275	106	264	9½EE	"	" 9½EE
Sock, wool, ski, 73-S34403	276	109	275	10EE	"	" 10EE
Sock, wool, cushion and sock, wool, ski	279	109	274	10¼EE+	"	" 10½EEE

The Reliability of Sensation in the Judgment of Fit:

4. It has been asserted that troops exhibit strong preference for shoes which fit snugly to their feet. Observations at the Laboratory suggest that this may not be entirely correct. Table 5 and Figure 5 show a comparison of the shoe sizes worn by troops when they arrived before the start of the present experiment with those sizes which they selected after its completion. Their selection was made on the basis of sensation only, each man being given a trial of several shoe sizes without being permitted to note the size designation within the shoe. It is noted that 23 of 29 men selected shoes which were wider or longer, or both, than the shoes which they had worn at the start of the test, while 11 men selected shoes which were wider although not longer or even as long as the Clark size designation. On the same Table, the shoe sizes may be compared with 3 dimensions of the feet of these subjects. A high degree of inconsistency is manifest.

TABLE 5

Comparison of Shoe Sizes Selected by Troops, on the Basis of Sensation,
 With (1) The Sizes Previously Worn
 With (2) Those Indicated by the Measuring Device, and
 With (3) The Actual Dimensions of the Men's Feet.

(Subjects arranged in order of increasing foot length)

NAME	<u>SIZE SELECTED</u>	<u>SIZE WORN WHEN TROOPS ARRIVED FOR TEST</u>	<u>SIZE INDICATED BY CLARK DEVICE</u>	<u>FOOT DIMENSIONS</u> <u>MM</u>		
				<u>LENGTH</u>	<u>WIDTH</u>	<u>BALL HEIGHT</u>
Fir	7D	7D	7½E	250	100	39
Lew	8EE	7½D	7½E	252	105	36
Rom	6½-3E	6½E	8EE	255	105	38
Cra	8E	7½E	8½E	257	102	37
Cru	7-3E	7½EE	8E	258	103	38
Sin	8½EE	8½D	8½EE	261	111	38
Vas	8½E	9C	8½D	262	103	36
Phi	8½E	9C	8½E	262	104	35
Woo	8EE	8D	8½D	263	102	37
Bar	9C	9C	9E	263	104	36
Tra	8-3E	7½EE	9D	266	102	36
Rus	9E	9D	9EE	267	108	38
Kna	8E	8D	9½C	268	101	38
Maya	8EE	9B	9E	268	102	33
Bro	9E	9C	9D	268	104	40
Cal	9D	10C	9EE	268	104	37
Wul	10-5E	9-4E	9-4E	268	114	40
Voz	9½E	10B	9E	272	105	38
Bak	9E	10D	10E	273	103	42
Wea	10E	10C	10E	274	105	42
Hav	9½EE	9½E	10E	275	111	37
Bel	9½E	9½D	10D	276	106	38
Dye	9½E	9½C	10D	277	103	39
Buf	10E	10C	11EE	280	101	41
Mel	9E	9D	10½C	280	104	39
Cam	10½E	10½C	10½E	281	110	38
Woh	11C	11½B	11½B	284	105	38
Mayb	10½D	10½C	11½E	286	110	38
Lys	11C	11C	12C	293	107	41

5. It appears that if an unfamiliar sizing nomenclature is used, soldiers may be fitted less snugly than their accustomed size choice without great resistance being encountered. Concerning this conclusion, the following should be borne in mind:

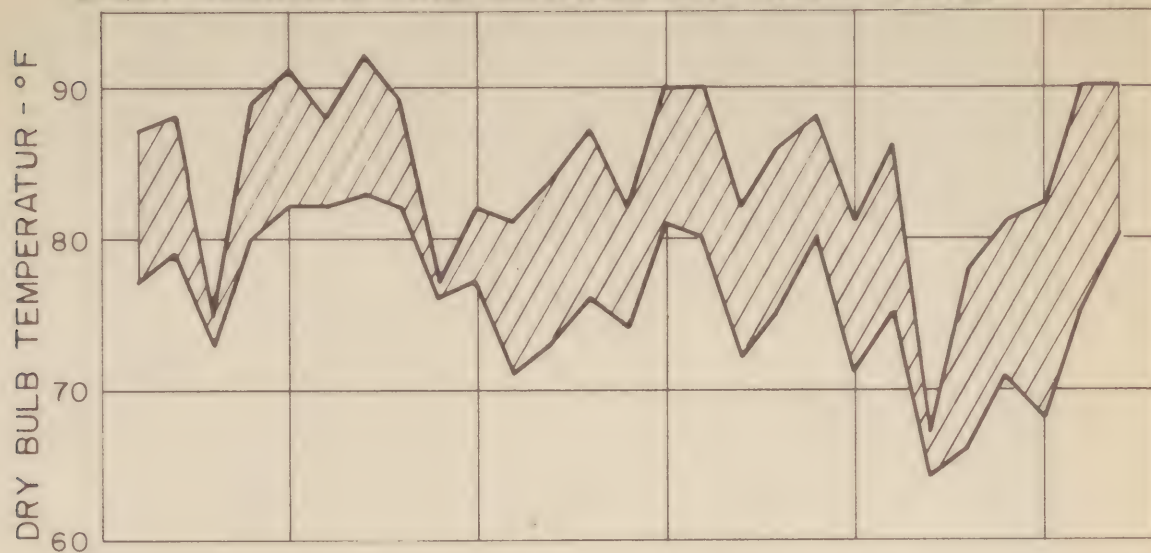
(1) That neither the Clark nor any other present device is necessarily expressive of the "proper" relationship between shoes and foot dimensions.

(2) That larger shoes may be rejected if the throat closure does not properly hold the foot in place even though still greater space for the forepart of the foot could be tolerated.

(3) That the shape of the shoe may not correspond to the shape of the foot and thus influence the judgment of fit on a basis other than size.

(4) That new shoes do not permit accurate interpretation of fit since new shoes, whether large or small, differ in their sensation of fit after they have been "broken in".

DAILY MAXIMUM AND MINIMUM DRY BULB TEMPERATURE



DAILY MAXIMUM AND MINIMUM RELATIVE HUMIDITY

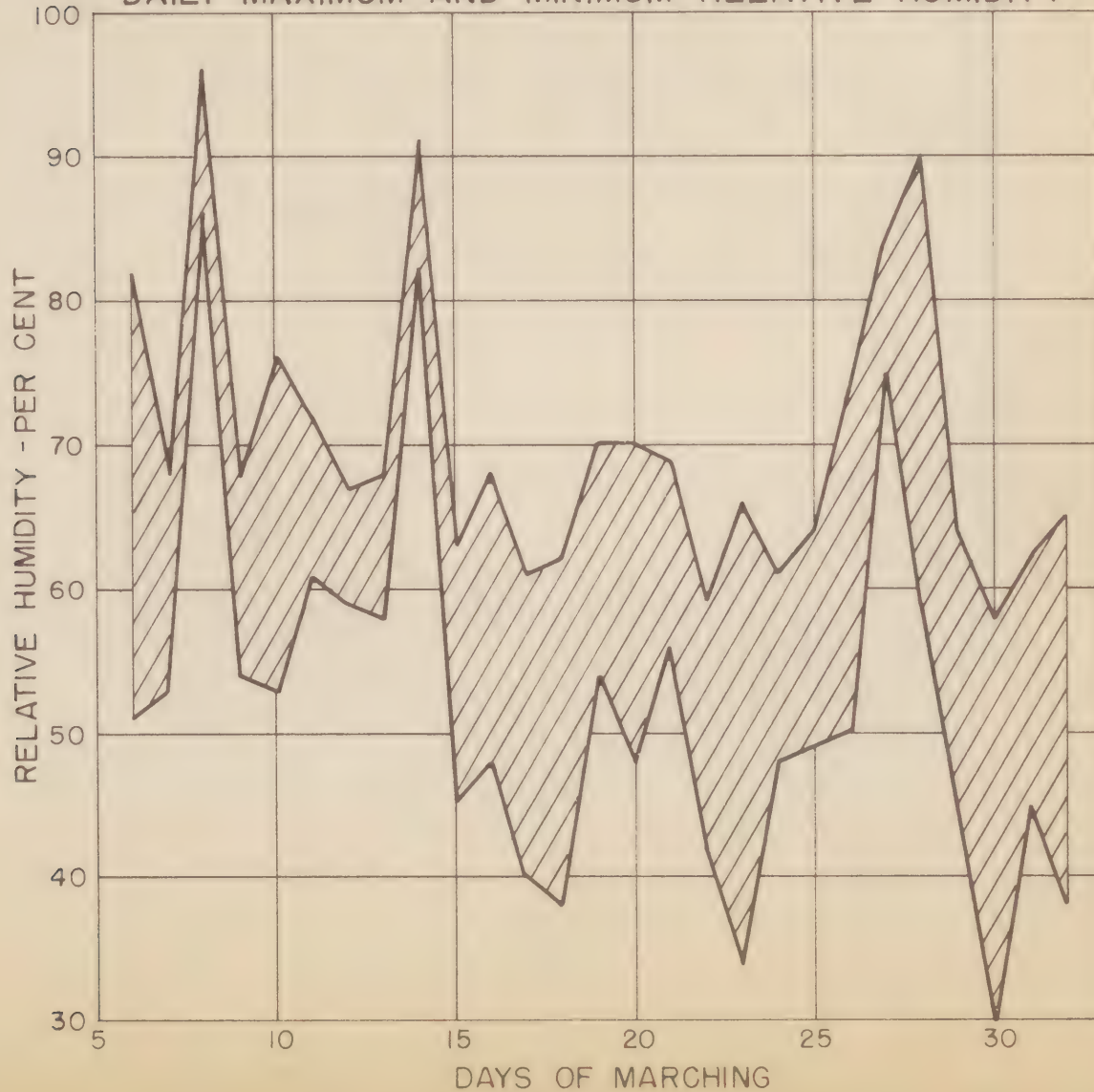


FIG. 1

FIG. 2

DISTRIBUTION OF CHANGES IN RIGHT FOOT
DIMENSIONS AFTER MARCH OF 13.7 MILES
(29 MEN)

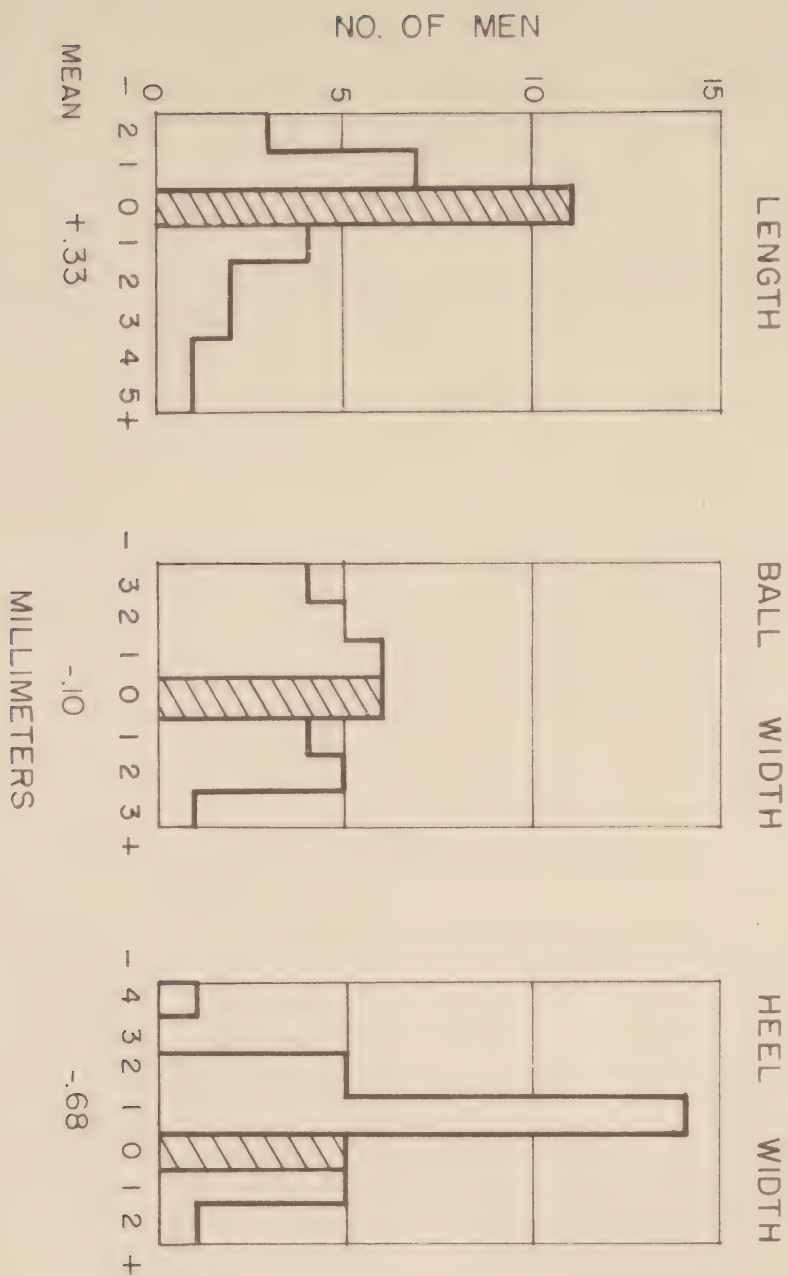


FIG. 2

FIG. 3

DISTRIBUTION OF CHANGES IN RIGHT FOOT
DIMENSIONS AFTER 32 DAYS OF MARCHING
(29 MEN)



FIG. 3

FIG. 4

DISTRIBUTION OF CHANGES IN RIGHT FOOT
DIMENSIONS WITH WEIGHT BEARING
20 KG. WEIGHT IN EACH HAND (88 LBS. TOTAL)
(29 MEN)

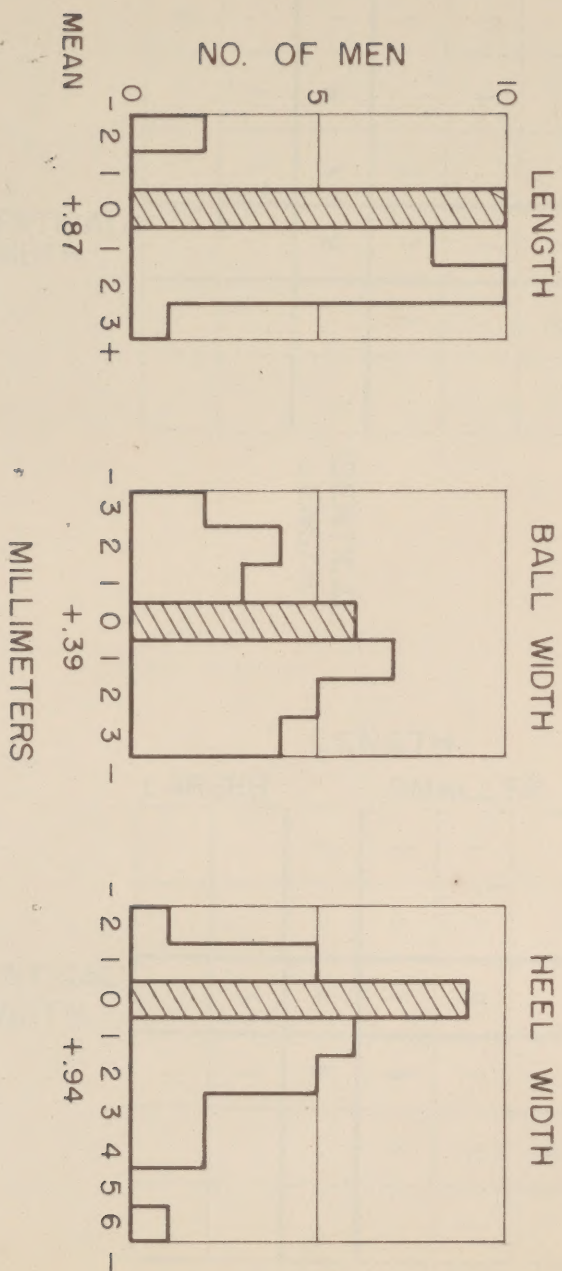


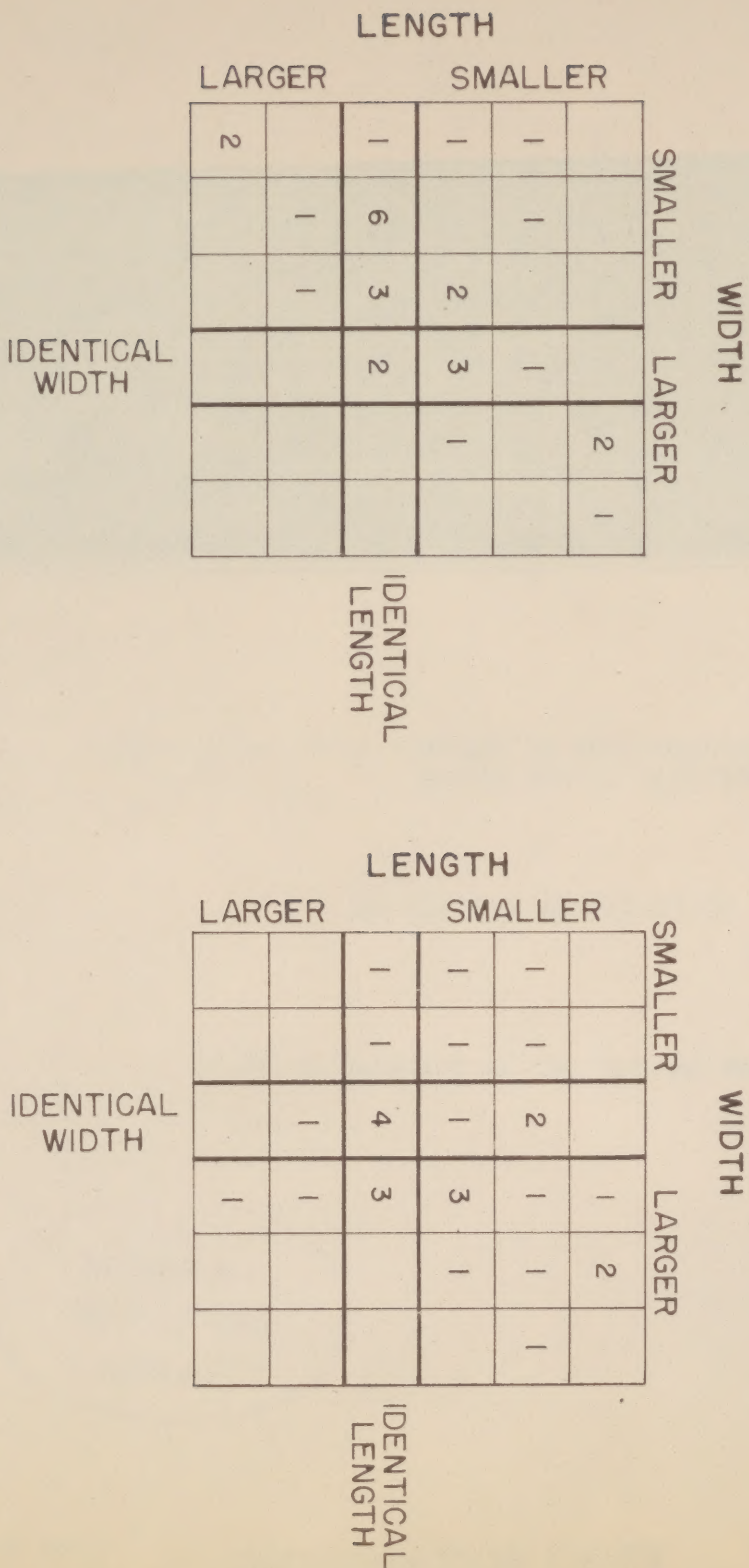
FIG. 4

FIG. 5

DISTRIBUTION OF DISAGREEMENT BETWEEN SIZE INDICATED
BY CLARK DEVICE AND

SIZE WORN WHEN TROOPS ARRIVED

SIZE SELECTED ON BASIS OF JUDGMENT
ALONE WITHOUT KNOWLEDGE OF SIZE
DESIGNATION AFTER 32 DAYS MARCHING



NOTE - EACH VERTICAL SEGMENT REPRESENTS $\frac{1}{2}$ SIZE IN LENGTH AND EACH
HORIZONTAL SEGMENT REPRESENTS ONE UNIT IN WIDTH.

FIG. 5

